Offshore mesoscale variability

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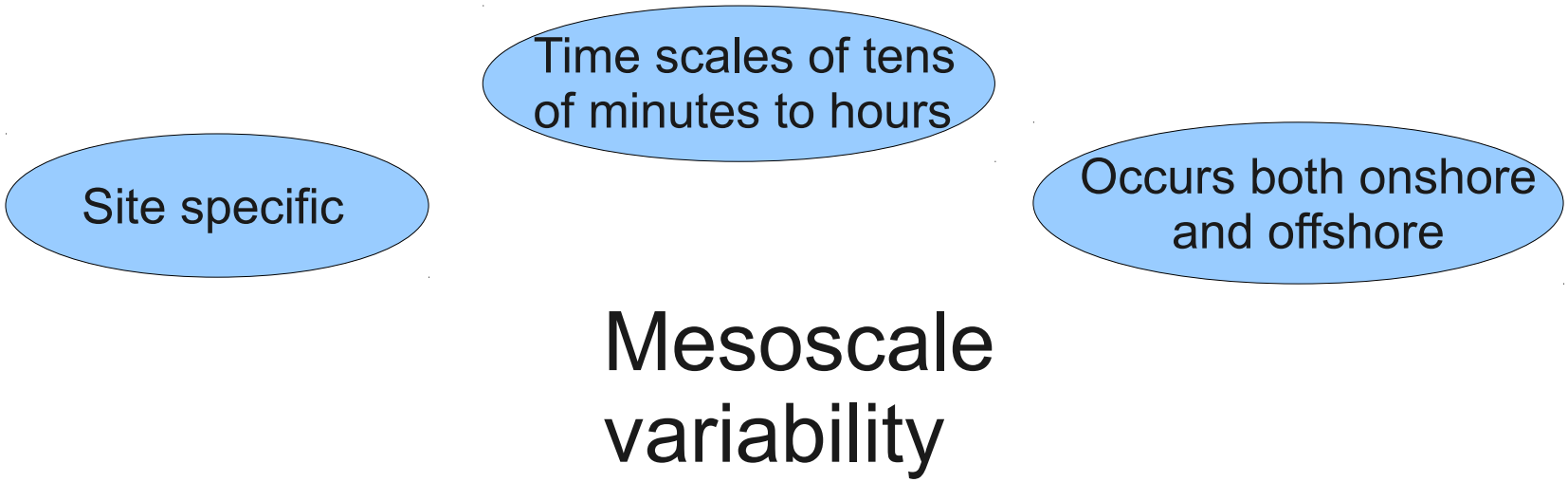
Why is mesoscale variability important to wind energy?



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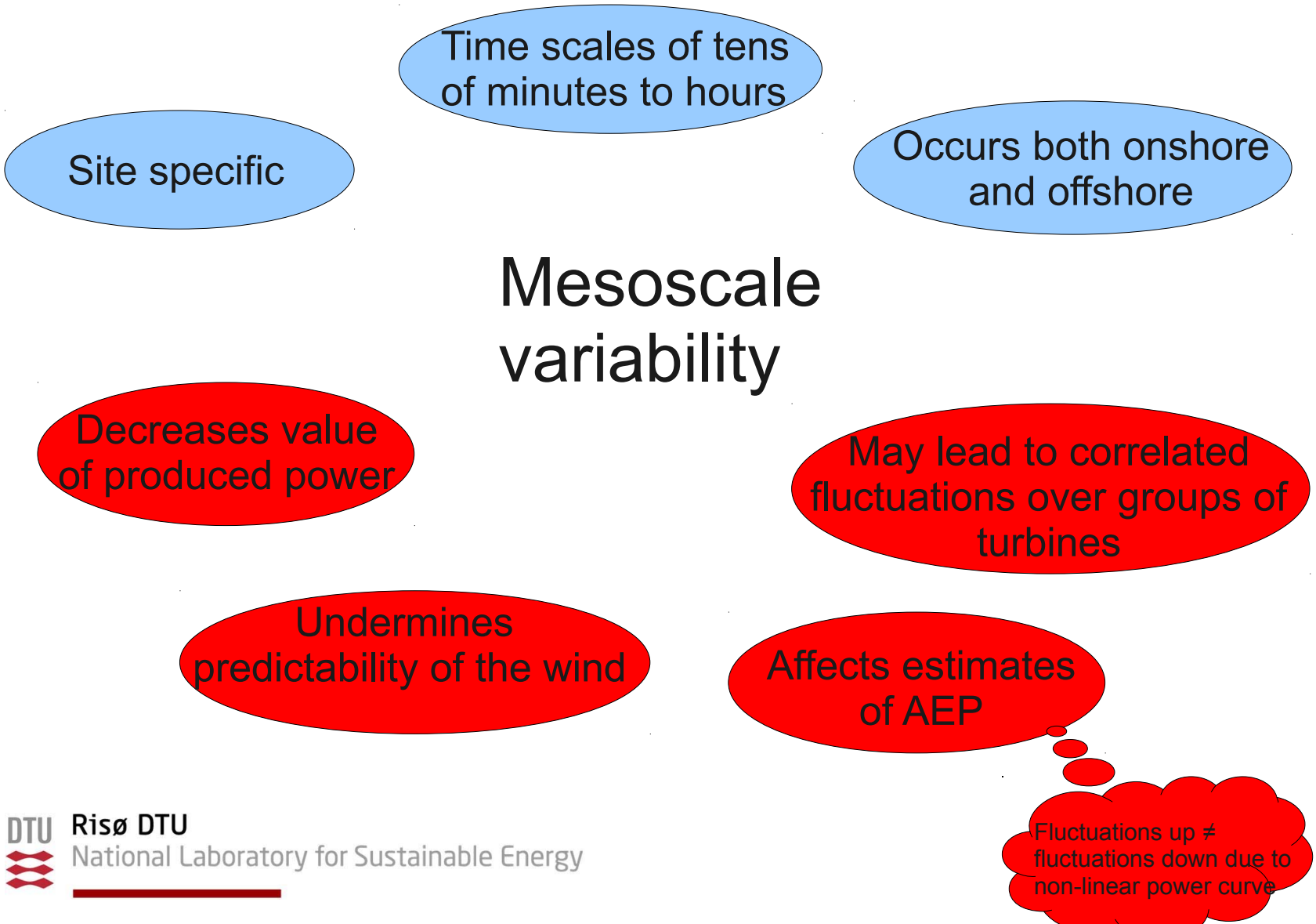
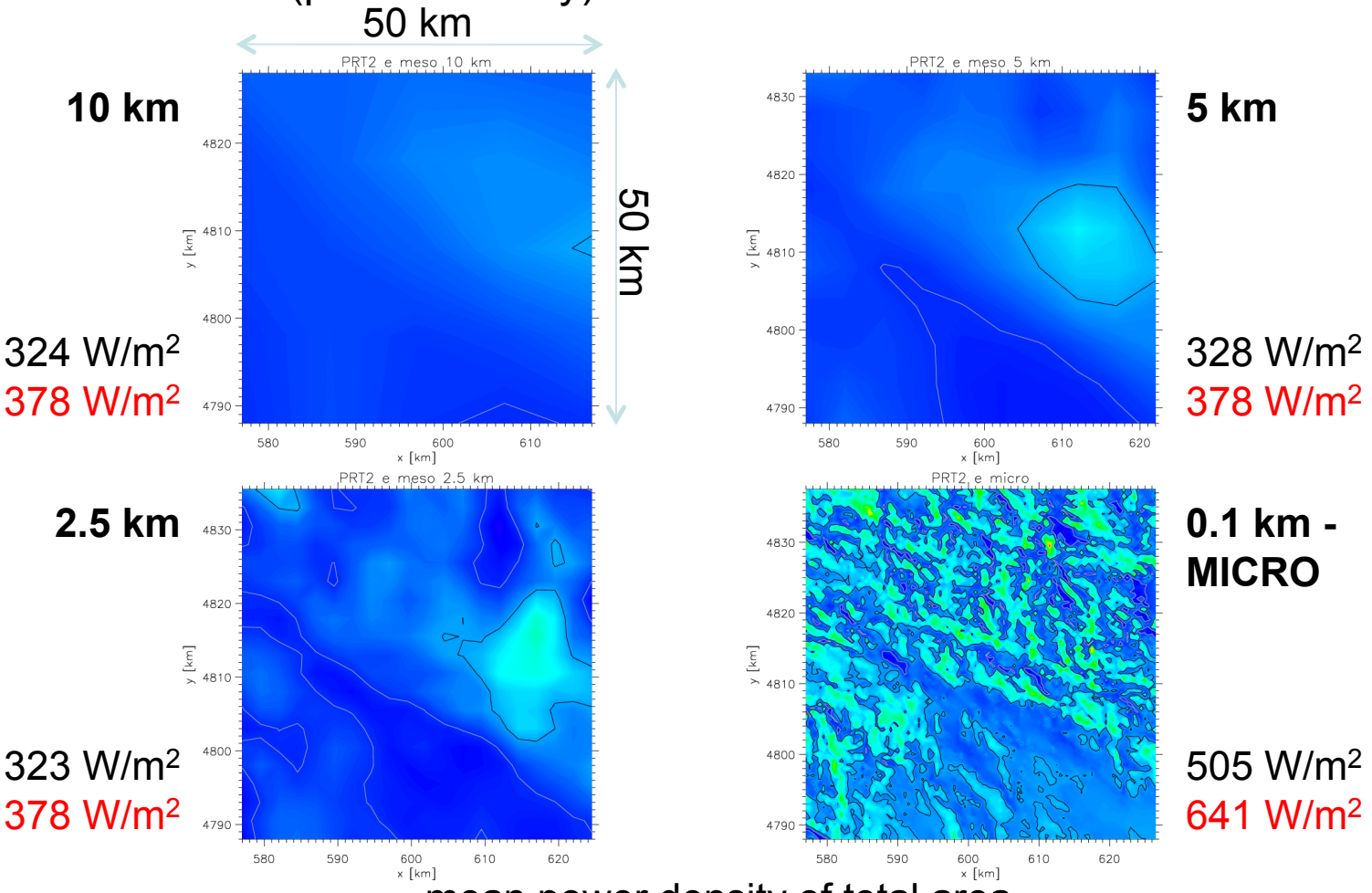


Outline

- Resolution and resource assessment onshore
- Mesoscale variability offshore
- Resolution and physics of mesoscale models offshore
- Power systems and control: spatial correlation offshore
- Conclusions

Importance of resolution

Wind resource (power density) calculated at different resolutions



mean power density of total area

mean power density for windiest 50% of area

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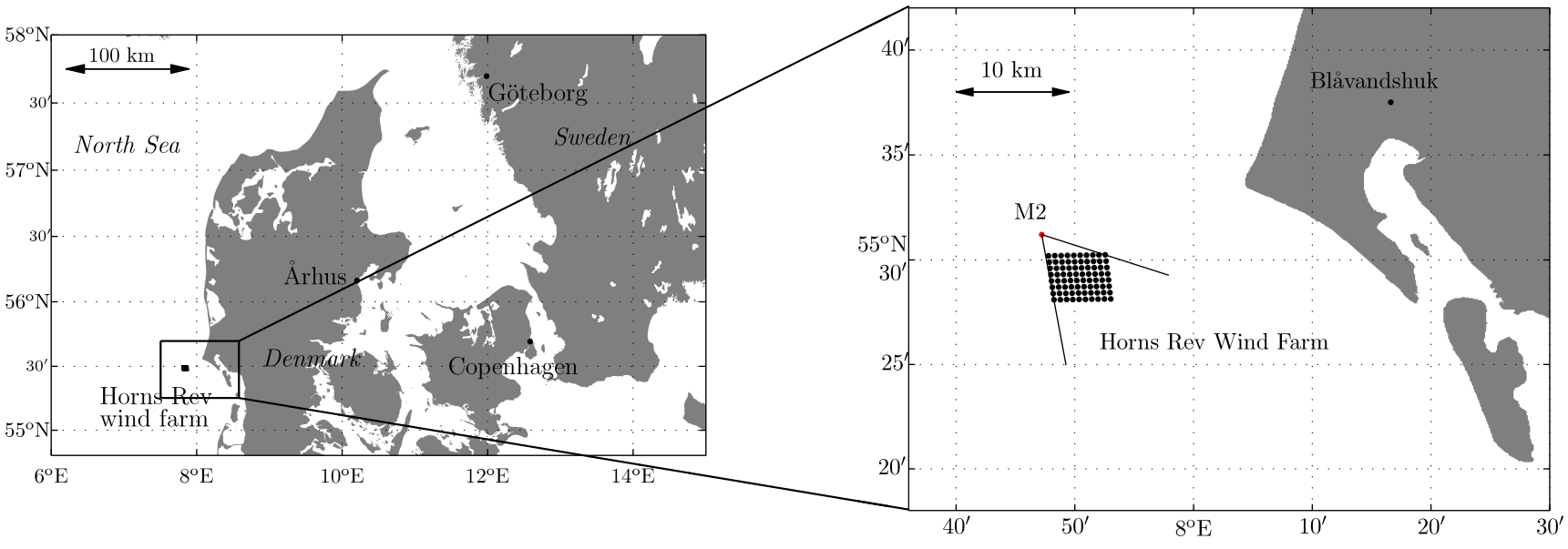
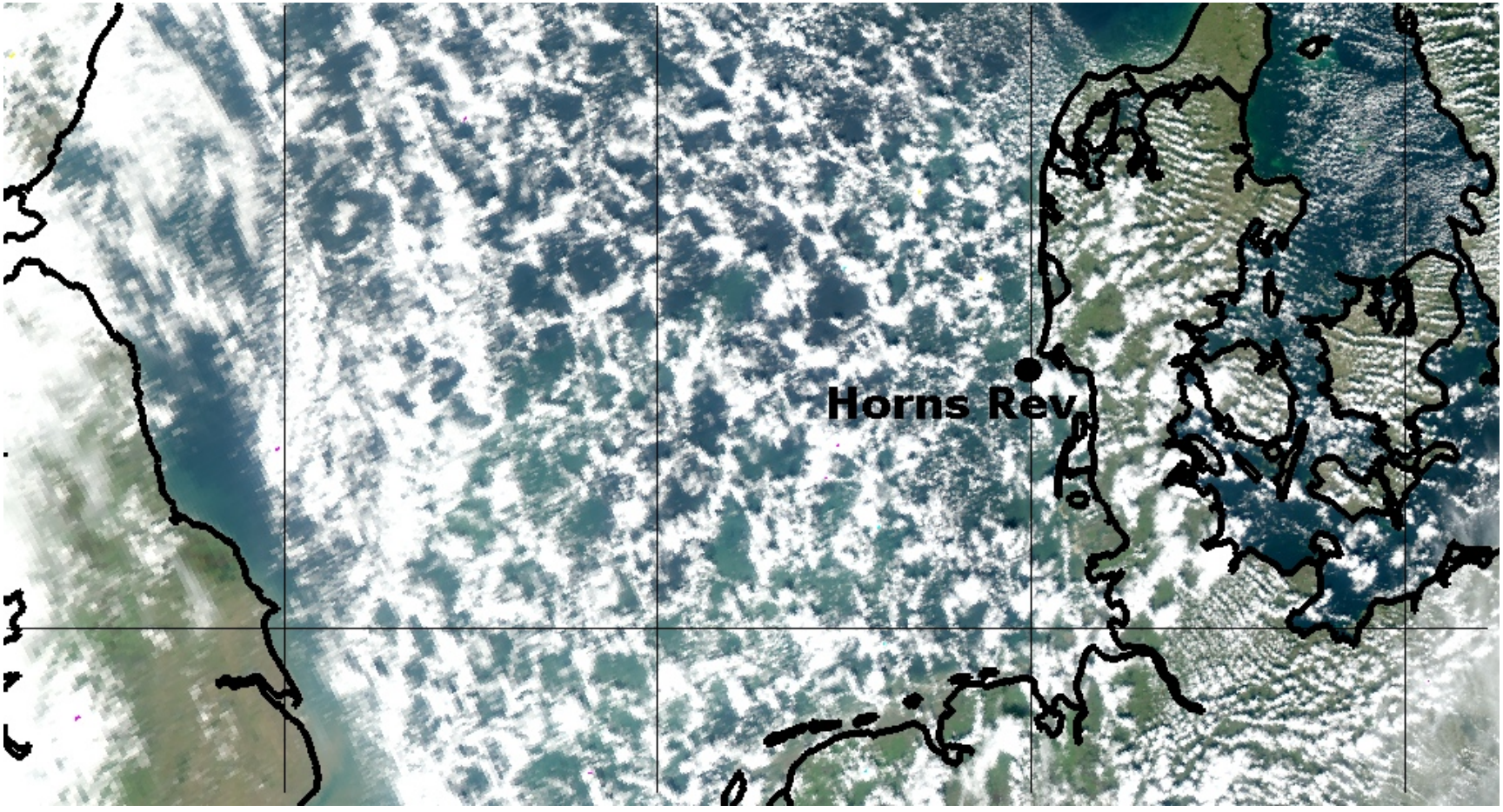
Jake Badger
Risø

The Horns Rev wind farm

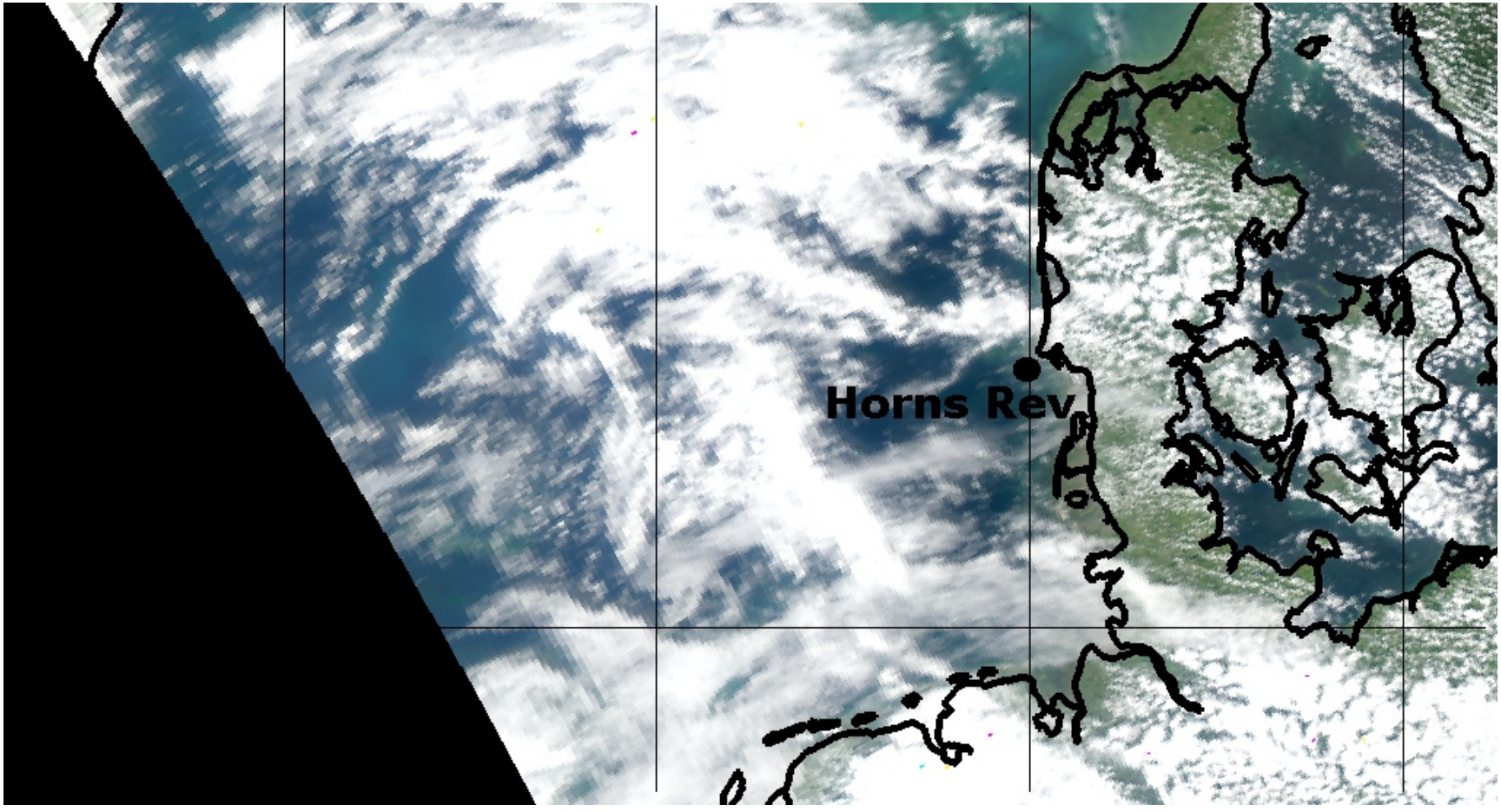


*Thank you to Dong Energy and Vattenfall for making Horns Rev met mast observations available

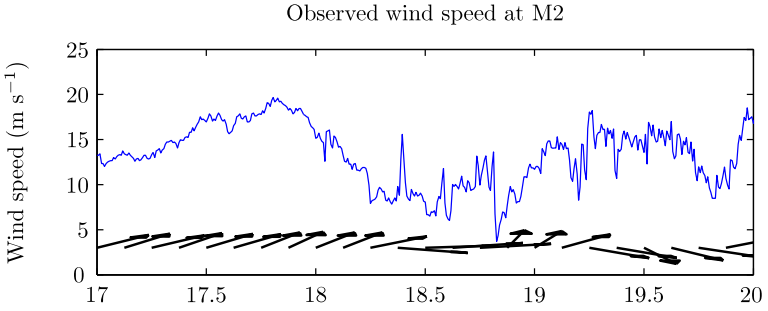
Mesoscale variability over the North Sea



Mesoscale variability over the North Sea

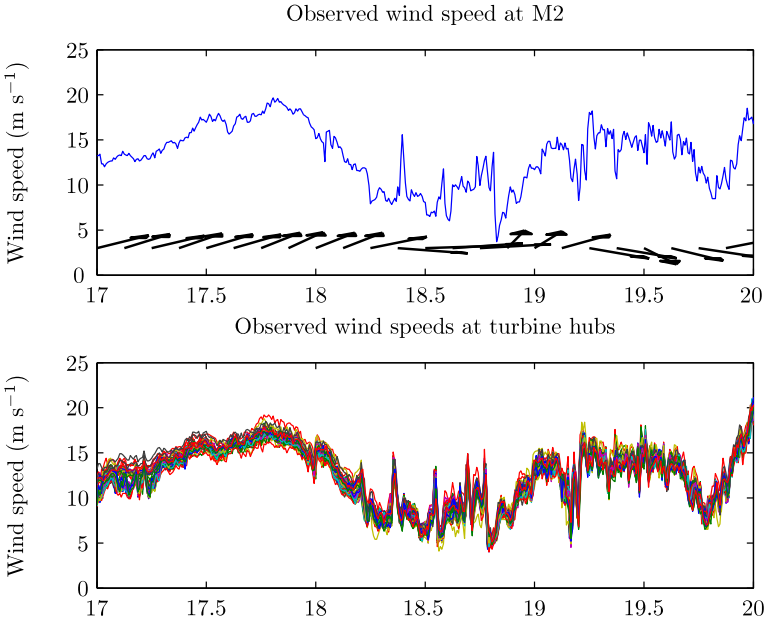


Motivation - I



→ **wind speed at 62 m met mast**

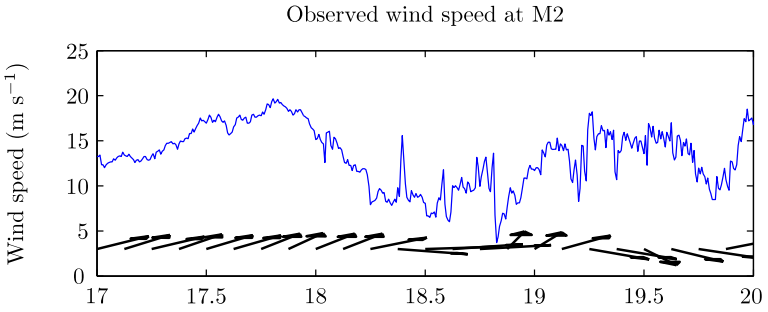
Motivation - I



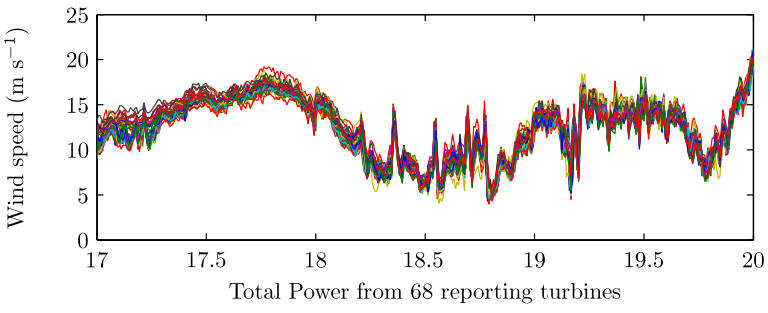
→ **wind speed at 62 m met mast**

→ **wind speeds at 70 m turbine hubs**

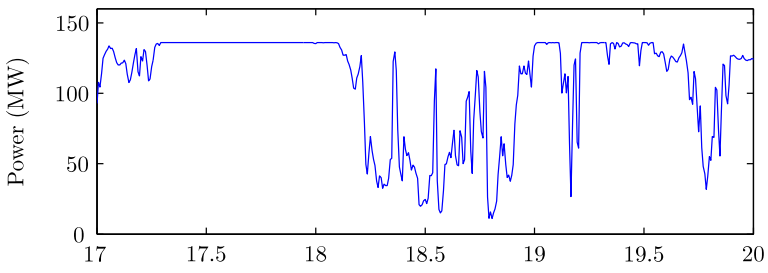
Motivation - I



→ **wind speed at 62 m met mast**

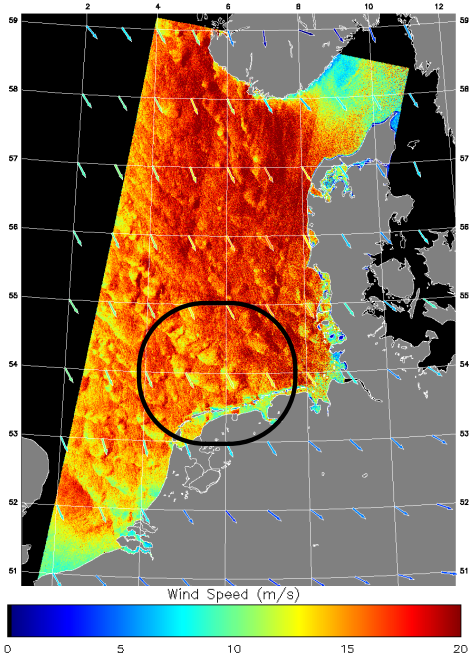


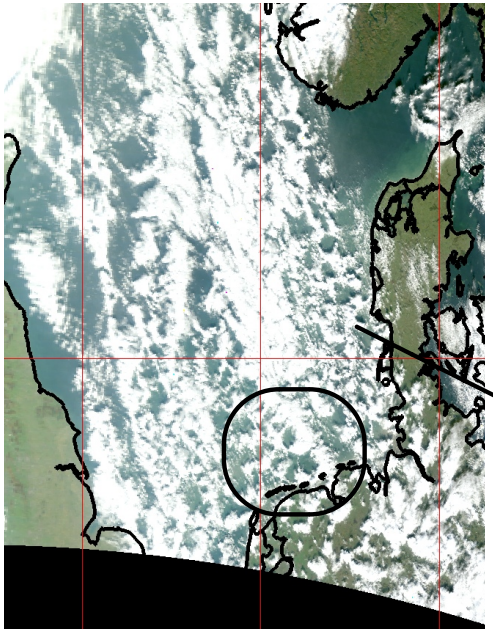
→ **wind speeds at 70 m turbine hubs**



→ **aggregate power from 68 turbines**

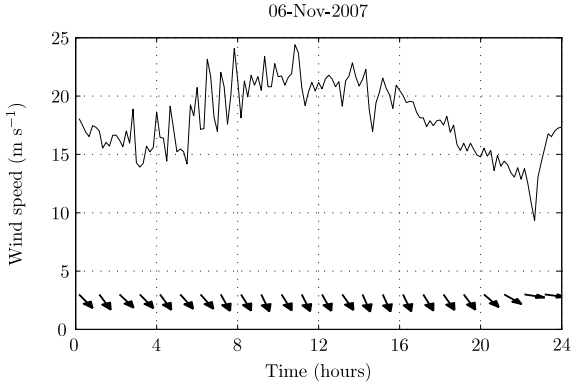
Mesoscale variability and large wind fluctuations

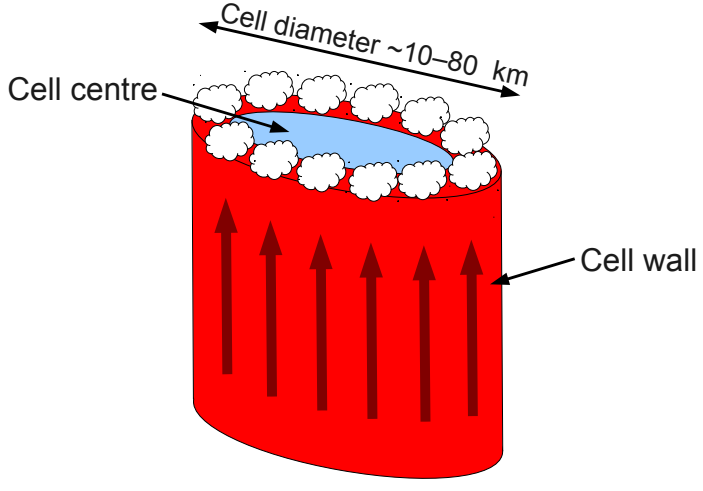




14 out of 19 severe wind variability days in 2003 occurred with OCC patterns observed over the North Sea

Open cellular Convection





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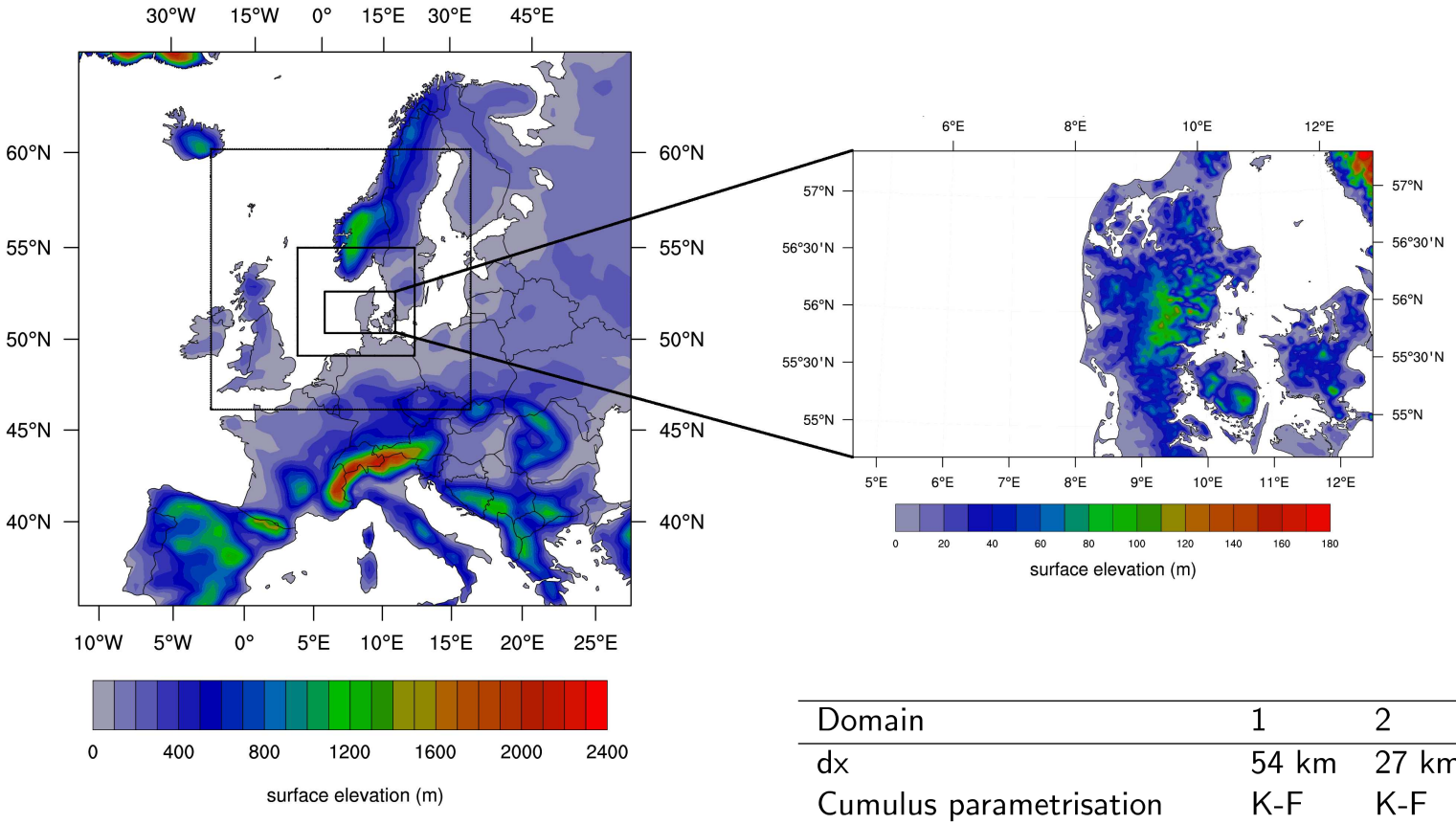
Mesoscale variability in a mesoscale model: WRF domains

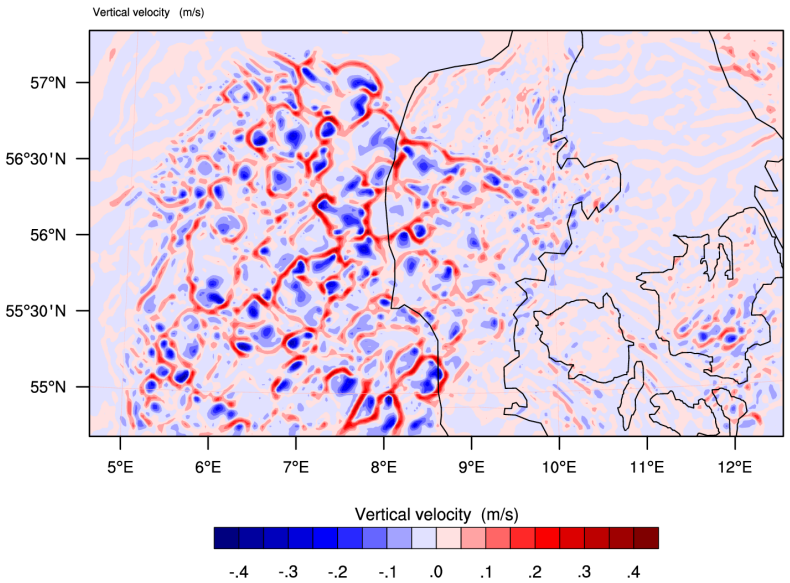


Domain	1	2	3	4
dx	54 km	27 km	6 km	2 km
Cumulus parametrisation	K-F	K-F	K-F	None
Vertical levels	37			
Microphysics scheme	Thompson et al scheme			
PBL physics	MYNN scheme			
Long-wave radiation physics	RRTM scheme			
Short-wave radiation physics	Dudhia scheme			
6th order diffusion	On			

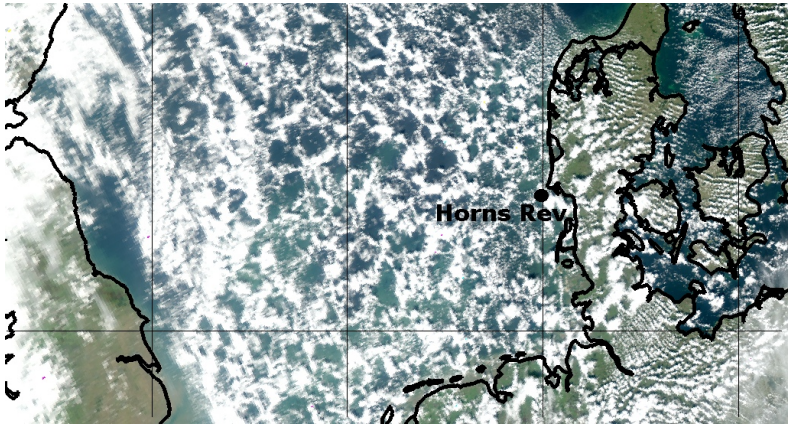
Mesoscale variability in WRF

WRF simulation hour 24 for domain 4:

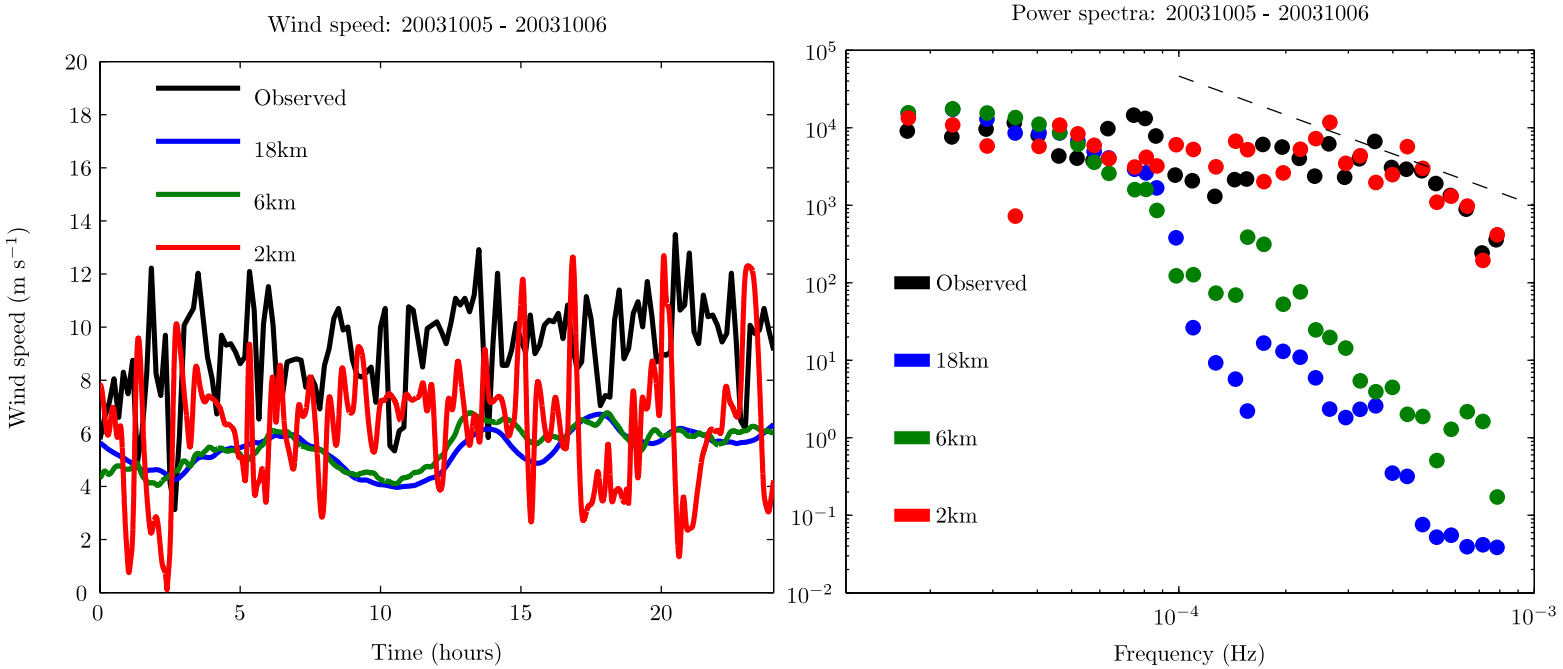
WRF (valid 20031005 1200 UTC)



MODIS image 20031005 1145 UTC

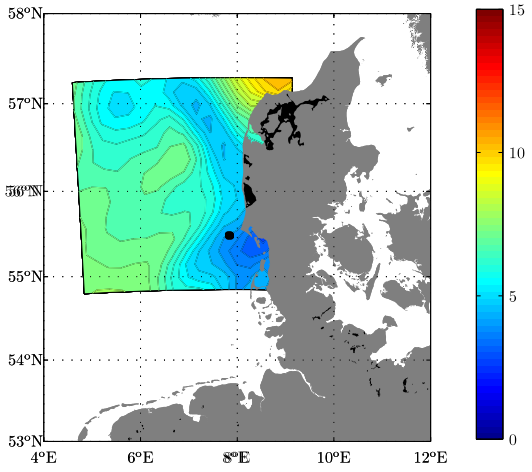


Observed and modelled time series

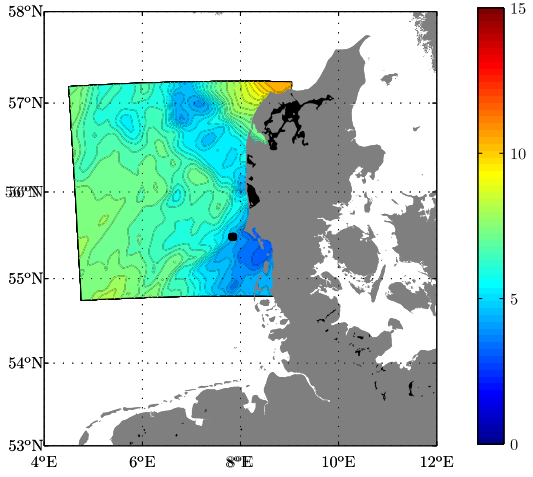


Mesoscale variability and model resolution

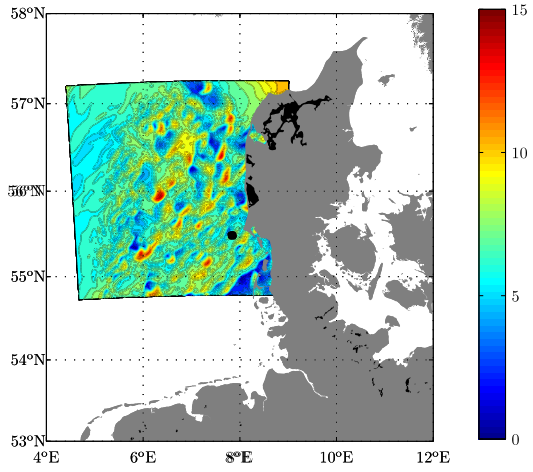
$\Delta x = 18km$



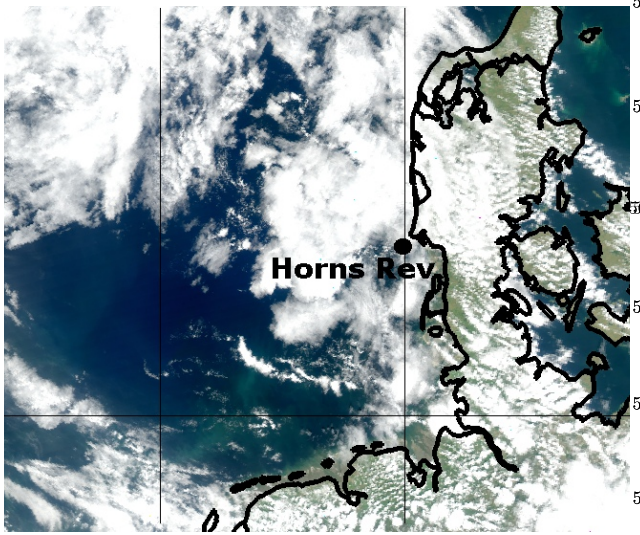
$\Delta x = 6km$



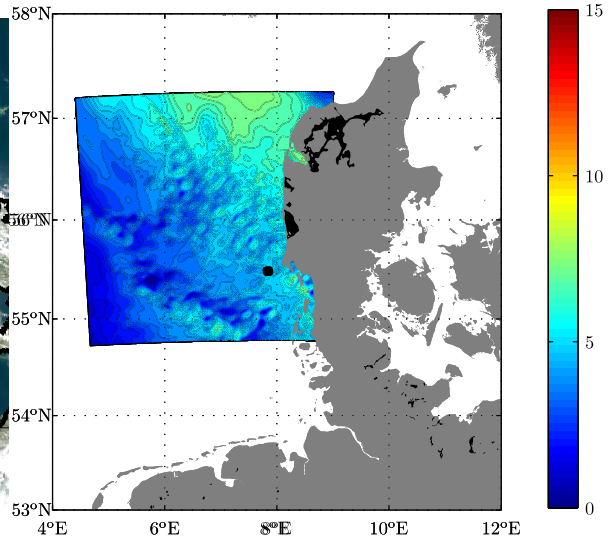
$\Delta x = 2km$



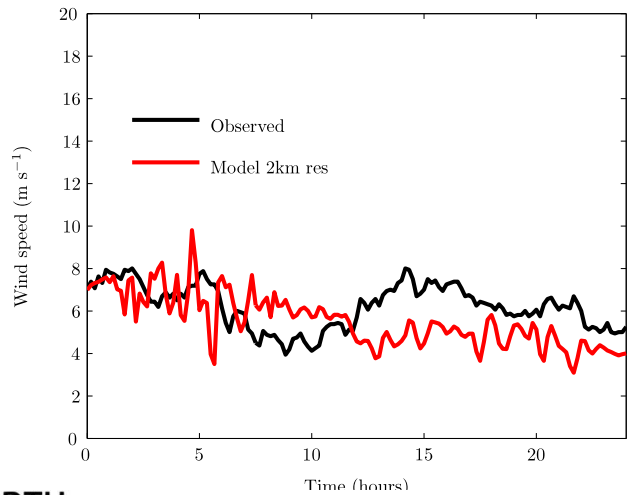
Unstable conditions with little mesoscale variability

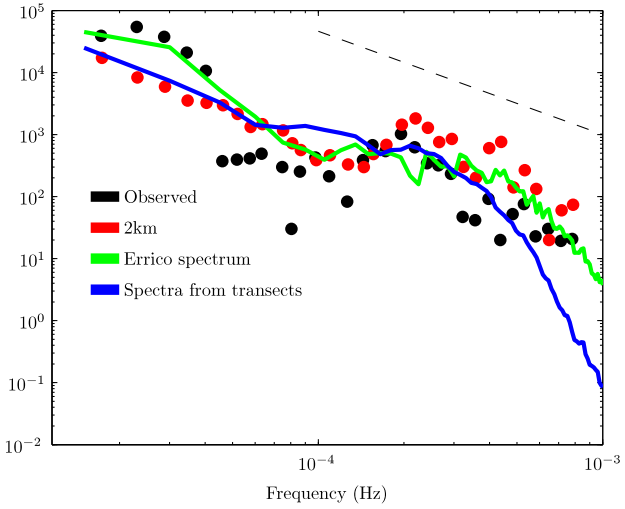


Wind speed: 20040727 00UTC - 20040728 00UTC



Power spectra: 20040727 00UTC - 20040728 00UTC





Summary

- Distinct features with a length scale 10s of km can strongly contribute to mesoscale variability
- Individual cases reveal model deficiencies / strengths which might be overlooked in long term verification
- To reproduce realistic mesoscale variability, the model must include the realistic physics
- Open cellular convection can cause large, hour-scale wind fluctuations of great relevance to wind energy
- We cannot predict or model the *phase* of the individual fluctuations . . .
- . . . but we can model the *statistical properties* of the time series

Variability and wind farm operation and control

- Mesoscale variability reduces the *predictability* of the power
- Mesoscale structures can have length scales of tens of km, so impact the whole wind farm simultaneously
- Sites subject of intense mesoscale variability are less *valuable* than sites with steady wind
- Spatially correlated wind speeds could lead to correlated power fluctuations at multiple wind farms

The normalised cross-spectrum

The *coherence* between time series at two points consists of contributions from in-phase and out-of-phase fluctuations.

$$Coherence = \frac{\overline{P_{12}}(f)}{\sqrt{\overline{P_1(f)P_2(f)}}}$$

$$= \frac{\overline{CO_{12}}(f) + i\overline{Qu_{12}}(f)}{\sqrt{\overline{P_1(f)P_2(f)}}}$$

co-spectrum: contributions from in-phase components

The normalised cross-spectrum

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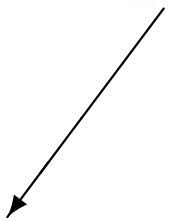
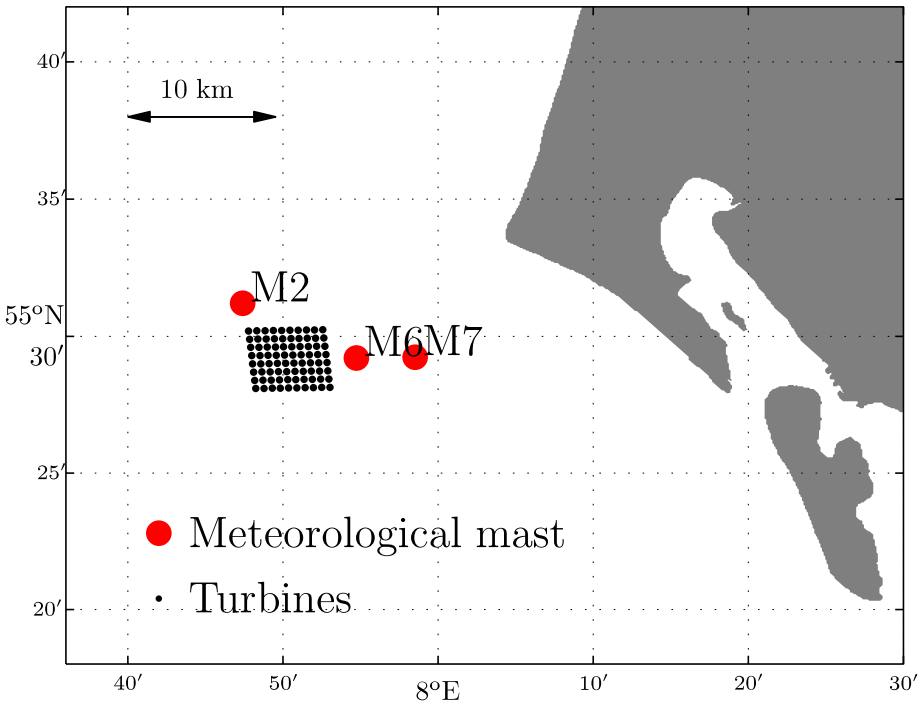


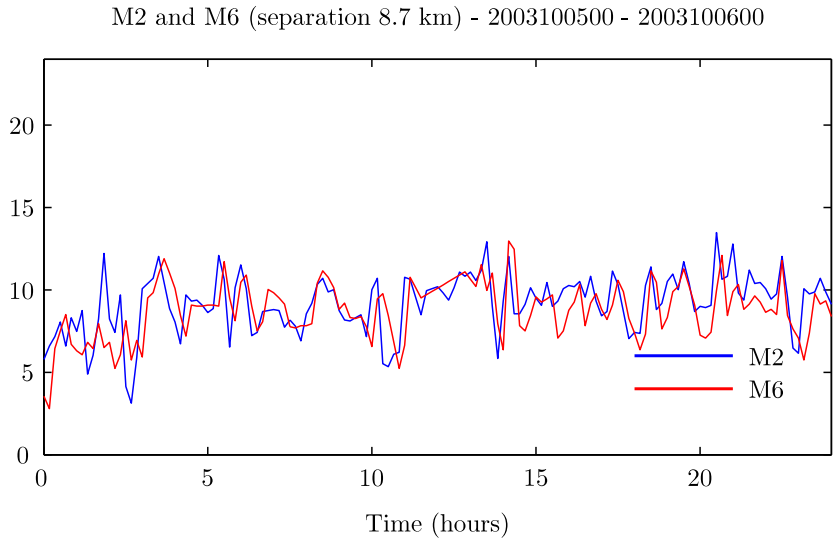
quadrature-spectrum: contributions from out-of-phase components

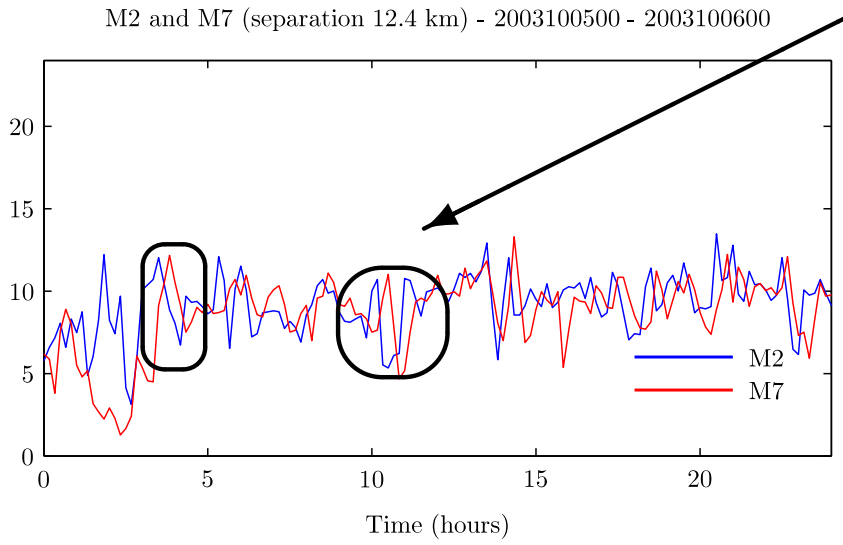
Meteorological masts at Horns Rev 1



- M2 and M6 separated by 8.7 km
- M2 and M7 separated by 12.4 km

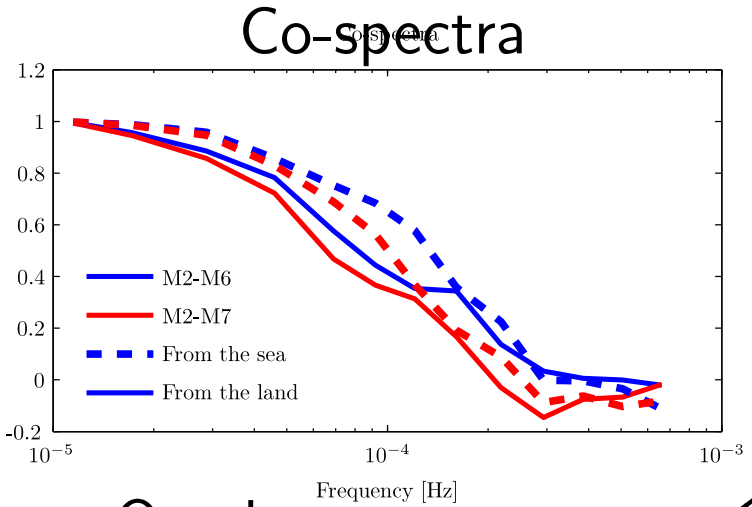
Observations from the three masts

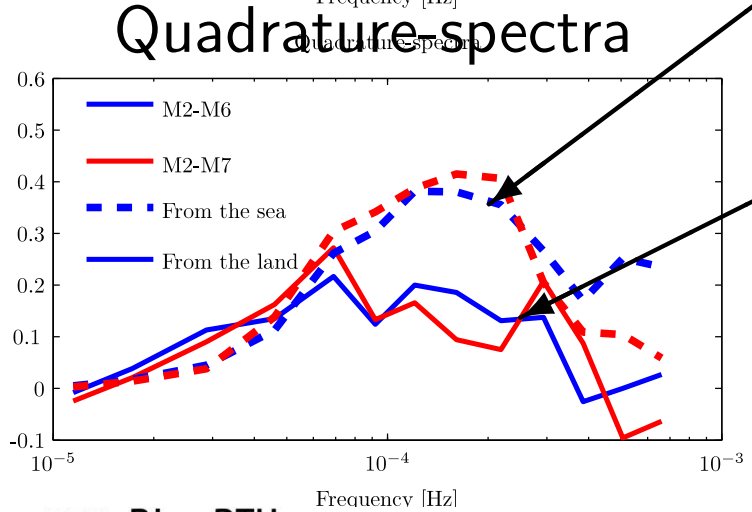




Fluctuations nearly 180° out of phase

Co- and quadrature spectra for 8.7 km and 12.4 km mast pairs





Wind direction from the sea

Wind direction from the land

Mesoscale coherence

- Different flow regimes for off-shore and on-shore flow
- Flow from the sea is more subject to correlated mesoscale variability
- Understanding the correlation structures necessary for power systems modelling
- Limited sets of paired data: Can mesoscale modelling fill the gaps?

Conclusions

Mesoscale variability is important to offshore wind energy because:

- large mesoscale wind fluctuations lead to large hour-scale power fluctuations
- mesoscale variability impacts the annual energy production of a site
- sites with climatologically lower mesoscale variability might turn out to be more valuable wind energy sites
- mesoscale variability undermines the hour-scale predictability of a site
- the correlation structure of the wind speed over large areas is an input to power systems planning